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Application of Ground Water Modeling in Development of Sustainable Water Resources Framework

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Abstract- Water has a determining role in every aspect of our life. Groundwater problems unfold slowly and incrementally, as the cumulative effect of many individual impacts of abstractions and contamination sources corroborate themselves. Monitoring & Effective groundwater resource management requires an optimum balancing of the increasing demands of water and long-term maintenance of the complex natural resource This paper reviews use of groundwater models in planning and developing the water harvesting structures including quality aspects of the groundwater and thereby predicting the fate and movement of the chemical in natural, urban or hypothetical scenario. The results show that Analytical and numerical groundwater flow models can be used in development of sustainable water resource framework if the proper sets of input variable are defined. The results of these evaluations indicate groundwater models can provide an efficient and readily-accessible tool to aid in designing systems for collection and storage of water.

Index Terms- groundwater, sustainable, flow, resource, variable

I. Introduction

The groundwater model is a representative scale model of a groundwater situation or aquifer which can be used to predict the effects of hydrological changes like groundwater abstraction for industrial purpose or irrigation development on the behavior of the aquifer. Nowadays the groundwater models are used in various water management plans for urban areas as well as in rural areas. As the computations in mathematical groundwater models are based on groundwater flow equations, which are differential equations that can often be solved only by approximate methods using a numerical analysis, these models are also called mathematical, numerical, or computational groundwater models. The purpose of modeling can vary widely, and the approach used may depend on site-specific needs, current understanding of the hydrogeological system, availability of input data, and expectation and use of the model results [(11)].

The principle for fundamental assumption of model is the conservation of masses (H.Darcy, 1856) [(1)]. Field investigations are essential for development of models. Results depend on the quality and quantity of the field data available to define input parameters and boundary conditions (Wang and Anderson, 1982) [(2)]. Modeling may be of limited value when a remedy can be readily identified, available data indicate there is not an environmental problem, or the site is too complex to model realistically. If a site is poorly characterized or poorly understood, any simulation of the transport and impacts of contaminants using models could be misleading. The use of models under such circumstances can help to support only limited types of decisions, such as planning and prioritizing activities. As a general rule, it is prudent to continually question the results of modeling and the potential consequences of decisions based on misleading results, and consider what can be done to verify results (U.S. EPA, 1996c) [(3)]. Because major decisions frequently are based on modeling results, it is essential that modeling be conducted in a manner that provides confidence that the results portray field conditions. Thus, the effort must be documented in detail.

This paper identifies fundamental types of models and the necessary documentation required for development of a water harvesting structure. We first describe the results from literature review, including a summary of selected codes and their capabilities, as well as an assessment of the types of hydrogeological conditions. The subsequent sections provide the approach for deciding which code might be most appropriate for a given modeling effort, and where we put the decision approach to practical use.

II. Principle

The concept of Sustainable development was first brought up in the Brundtland report (WCED, 1987). It is defined as the development which meets the need of the present generation without compromising the ability of future generation to meet its need [(4)]. When a development project begins in an area then the rate of extraction gets higher than the rate of recharge which results in continual lowering of water level. Hence, the emphasis of groundwater management practice has to be utilized in an efficient and sustainable manner contributing to the economic and social well-being of the community. A sustainable groundwater development depends on the understanding of processes in the aquifer system, quantitative and qualitative monitoring of the resource and the interaction with land and surface water development [(5)]. The following key principles reflect different aspects of concern in the evolution of sustainability in groundwater development:

i. Conservation of groundwater resources;
ii. Protection of groundwater quality; and
iii. Consideration of environmental impacts

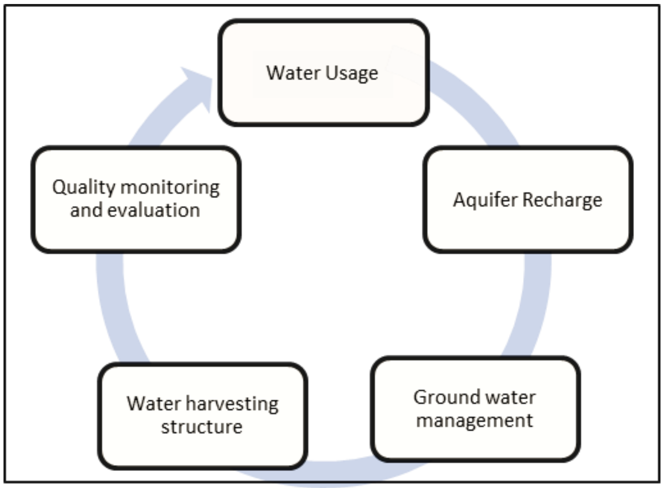

Figure 1: Ground Water sustainability cycle

The movement of groundwater through porous media is described by the following partial differential equation, which is based on Darcy's law and the conservation of mass (McDonald and Harbaugh, 1988) [(6)]:

$$\frac{\delta}{\delta x}\left(Kxx\frac{\delta h}{\delta x}\right)+\frac{\delta}{\delta y}\left(Kyy\frac{\delta h}{\delta y}\right)+\frac{\delta}{\delta z}\left(Kzz\frac{\delta h}{\delta z}\right)-W=Ss\frac{\delta h}{\delta t}$$

where,

Kxx, **Kyy** and **Kzz** are values of hydraulic conductivity in the x, y, and z directions along Cartesian coordinate axes, which are assumes to align with the principal directions of hydraulic conductivity (LT^{-1}),

h is the hydraulic head (L),

W is a volumetric flux per unit volume and represents sinks and/or sources (T^{-1}),

Ss is the specific storage of the porous material (L^{-1}), and

t is time(T).

2.1 Classification

Models can be based on a single equation or a set of governing equations that represent the processes occurring like ground water flow, solute transport, etc. [(7)]. They can be classified as analytical or numerical, deterministic or stochastic, or steady state or transient. In addition, models can be one, two, or three-dimensional.

a. Analytical Models

Analytical models are generally based on precise solutions to one or two-dimensional ground water flow or transport equations. These equations are simplified forms of more complex three-dimensional ground water flow and solute transport equations used in numerical modeling. Analytical models require basic fundamental information of the flow system, including a horizontal aquifer base, uniform hydraulic and chemical reaction properties, and simple flow or chemical reaction boundaries. In addition, analytical models are typically steady-state and one-dimensional, or two-dimensional. Analytical models are best used when designing data collection plans prior to beginning field activities or as an independent check of numerical model results.

b. Numerical models

Numerical models solve the partial differential flow or solute transport equations through numerical approximations using matrix algebra and discretization of the modeled domain. The accuracy of numerical models depends on the model input data, the size of the space and time discretization, and the numerical method used to solve the model equations. Where the ground water system is very complex, and where sufficient data exist to simulate the complexities in detail, a numerical model may be able to simulate the system with greater accuracy. Generally, they can be used to model irregular boundaries, variations in input parameters such as hydraulic conductivity and recharge, vertical flow gradients at recharge and discharge areas, transient flow conditions, complex multilayered hydrogeological framework, and other complexities. Numerical models are best used when the field data shows that ground water flow or transport processes are relatively complex and ground water flow direction, hydrogeological or geochemical conditions, and hydraulic or chemical sources are sinks that vary with time and space.

2.2 Selection of an appropriate Model

A variety of ground water flow model are available now and they are used quite extensively to design and evaluate the impact of the groundwater withdrawal systems. The selection of a model is done in three steps

a. Model Selection Process

Construction of an appropriate model at the site
Code selection
Model Evaluation

The three important factors that must be considered while choosing an appropriate model code are

i. Site Environmental Characteristics
ii. Demography and land use
iii. Contamination characteristics(if present)

Successful ground-water modeling requires the selection of a computer code that is not only consistent with the site characteristics but also with the modeling objectives. The most common code selection mistakes are selecting codes that are more sophisticated than are appropriate for the available data or the level of the result desired, and the application of a less sophisticated code that does not account for the flow and transport processes that dominate the system [(10)].

b. The Code Selection Process

To meet the specific modeling needs there are several suitable computer codes that could potentially be chosen from a large number of published codes presented in the scientific literature[(9)]. Ideally, each candidate code should be evaluated in detail to identify the one most appropriate for the particular site and modeling objectives. However, the resources to complete a detailed study are seldom available, and usually only one to two codes are selected based upon a cursory review of code capabilities and the experience of the modeler.

Regardless of whether a detailed or more cursory review is performed, it is important for the user to be cognizant of the following factors and how they will affect code selection:

i. Code Capabilities consistent with: User needs Modeling objectives, Site characteristics, Contaminant characteristics, Quality and quantity of data
ii. Code Testing involves: Documentation, Verification, Validation
iii. History of Use Acceptance: Theoretically, the reviewer should obtain a copy of the computer code, learn to use the code, select a set of verification problems with known answers, and compare the results of the model to the benchmark problems.

c. Model Validation

Model validation, which involves checking the model predictions against independent field investigations designed specifically to test the accuracy of the model, would almost never be practical during the code evaluation and selection process

2.3 Application

The Department of Agriculture, Punjab carried out a ground water study for irrigartion purpose. The study area is from Indo Gangetic basin. It covers Farozpur, Muktsar and Faridhot(approximately 651,079 hectares). The annual rainfall is 300 mm and the soil present is alluvial deposits. Irrigation is carried out by canal and ground water. To monitor the depth of ground water table 60 observation wells were installed by Groundwater Cell of Department of Agriculture, Punjab. Observation was taken twice a year during June (Pre monsoon period) and October (Post monsoon period) [(8)].

Based on June/October water level contour maps were drawn and 10km X 10km grids were superimposed on it. For computing sources/sink terms, the draft and discharge was distributed to various cells. Inputs included water requirement of crops, canal and tube wells, water availability and ground water quality. In this study the quality of water was divided into five categories <2.0, 3.0, 4.0, 5.0 and 6.0 dS/m.

A water allocation model was developed to maximize ground water pumpage considering the input parameters and hydraulic head [(8)]. The maximum discharge is given by the equation

$$Max\ Z = \sum_{i=1}^{14} . \sum_{j=1}^{11} Qi,j$$

Where Z= Total discharge at all nodes,
Q_{ij} = Tube well discharge at i^{th} row and j^{th} column
i= number of rows; j= number of columns
$h_{i,j} <= R_{i,j} - X$
$h_{i,j} >= R_{i,j} - Y$
$R_{i,j}$- reduced level
X= upper limit of the water table depth (m)
Y=lower limit of the water table depth

A two dimensional transient flow equation was used and the ground water variables were incorporated as decision variable in management model. Hydraulic constraints at all nodes were added in the model so that the water level would not rise or fall under specified limit.

Actual irrigation was found at 90% level of evaporation transpiration constraints. A number of simulations run were then carried out to maximize pumping to raise the water table. The simulation optimization results under water table <2m in parts of Jaladabad and Muktsar whereas declining table trend was observed in Fazilka, Khuian Sarwar and Abohar. The declining water table in the area was controlled by reducing the pumping in the area. The problem of area having water table depth<2m was solved by increasing the pumping limit to maximum possible discharge limit.

III. Conclusion

Ground water is an important natural resource and should be utilized in a manner that both quantity and quality problems is avoided. The key principles in developing a sustainable ground water frame work are conservation of groundwater resources, protection of groundwater quality and consideration of environmental impacts. Mathematical models provide a quantitative framework to synthesize data of a ground water system and it plays an important role in understanding the water systems behavior when subjected to stress and changing conditions. The complex systems require special efforts to develop the monitoring network and monitoring tools for predictive analysis.

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